Condition of *Barbus sclateri* from semi-arid aquatic systems: effects of habitat quality disturbances

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This study investigated the relationships between fish condition and environmental variables in *Barbus sclateri* from semi-arid freshwater ecosystems in the south-eastern Iberian Peninsula. Two main habitats were studied: semi-arid streams characterized by strong seasonal fluctuations in flow level (droughts and floods) and reservoirs (artificial ecosystems characterised by waters of high conductivity). The mass–length relationships were used to test differences in fish condition between nine stream populations and five reservoir populations of *B. sclateri* from the Segura River basin. The relationships between seven ecosystem variables (conductivity, oxygen concentration, water temperature, pH, seasonal water flow, submerged vegetation and sub-basin location) and fish condition were analysed. The ecological variables that accounted for most of the variation in fish condition were seasonal water fluctuation and water conductivity. The condition of *B. sclateri* populations may be a good indicator of fish habitat quality in Mediterranean semi-arid freshwater ecosystems and should be considered when such populations are subjected to sports fishing regulations, recovery plans or any other management programme. © 2003 The Fisheries Society of the British Isles

Key words: *Barbus sclateri*; endemic fish; environmental assessment; habitat differences.

INTRODUCTION

The semi-arid regions of the Mediterranean basin are exposed to climatic conditions, which have resulted in the development of an agricultural system dependent on irrigation. Associated with such development, there has been a great modification of superficial hydrology by engineering projects. In the south-east of Spain, this has resulted in a high number of reservoirs and a severe flow regulation of river systems.

Although these measures are rightly considered to be one of the main negative factors affecting Spanish fish fauna (Elvira, 1996), the direct impact on the native fish fauna of such engineering works has not been sufficiently analysed (Granado-Lorencio, 1992). The ecological study of the ichthyofauna confined in

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reservoirs compared with their counterparts inhabiting streams is of high scientific value, because this constitutes a natural reference for investigating adaptations adopted by species (Granado-Lorencio *et al.*, 1998).

The analysis of fish condition is standard practice in the management of fish populations, as a measure of both individual and cohort (*e.g.* age or size group) fitness (Jakob *et al.*, 1996). Measures of condition are generally intended to be indicators of tissue energy reserves and may characterize components of the environment in which the fish lives (*e.g.* habitat, prey availability and competition) (Vila-Gispert *et al.*, 2000; Vila-Gispert & Moreno-Amich, 2001). In this way, measures or indices of fish condition are of value to fishery managers, who must assess population status, the impact of management actions and anthropogenic influences on the resource they are managing (Brown & Austin, 1996). The mass–length relationship may provide an indirect means of evaluating ecological conditions and the effects of management strategies (Vila-Gispert *et al.*, 2000).

The present study compares fish condition, estimated from mass–length relationships, of 14 populations of barbel *Barbus sclateri* Günther from streams and reservoirs within the Segura River basin. There is a widespread need to increase knowledge of the life history characteristics of fishes under threat as a necessary tool for management actions and conservation programmes (Wootton *et al.*, 2000).

MATERIALS AND METHODS

STUDY AREA

The fish populations studied inhabited five streams with different hydrological regimes and five reservoirs located in one eco-geographical sector (Mas, 1986; Vidal-Abarca *et al.*, 1990) of the Segura River basin, which covers a drainage area of *c.* 14 432 km^2 (Fig. 1). This river basin is in the most semi-arid zone of the Iberian Peninsula (Vidal-Abarca *et al.*, 1987) and, probably, of Europe (Geiger, 1973). The eco-geographical sector is characterized by 300–400 mm annual precipitation, 8–9 months of negative water balance and hydrological cycles severely disturbed by flash floods. Therefore, the singularity of the sampled aquatic systems arises from the hydrological regimes, which are very variable on both a spatial and temporal scale.

The term 'semi-arid' is applied to regions where the water balance is negative, creating an environmental stress which, unlike those occurring in arid lands or deserts, is neither permanent nor predictable (Vidal-Abarca *et al.*, 1992). Semi-arid streams in the area are subject to natural disturbances (droughts and floods), as a consequence of their irregular hydrological regime on both annual and pluri-annual scales. The sampling reservoirs are included in Group IV of the ecological classification of Margalef (1976), and are characterized by waters of high conductivity (50–3600 μs cm^{-1}), mainly due to high concentrations of chlorides.

STUDY SPECIES AND SAMPLING METHODS

Barbus sclateri is an abundant endemic fish in the aquatic systems of the mid-south of the Iberian Peninsula, including the Guadiana, Guadalquivir and Segura Rivers basins (Elvira, 1995; Doadrio, 2001), and is included as 'vulnerable' in several regional Red Lists. This benthic species reproduces between May and July (Herrera & Fernández-Delgado, 1992; Torralva *et al.*, 1997; Soriguer *et al.*, 2000).
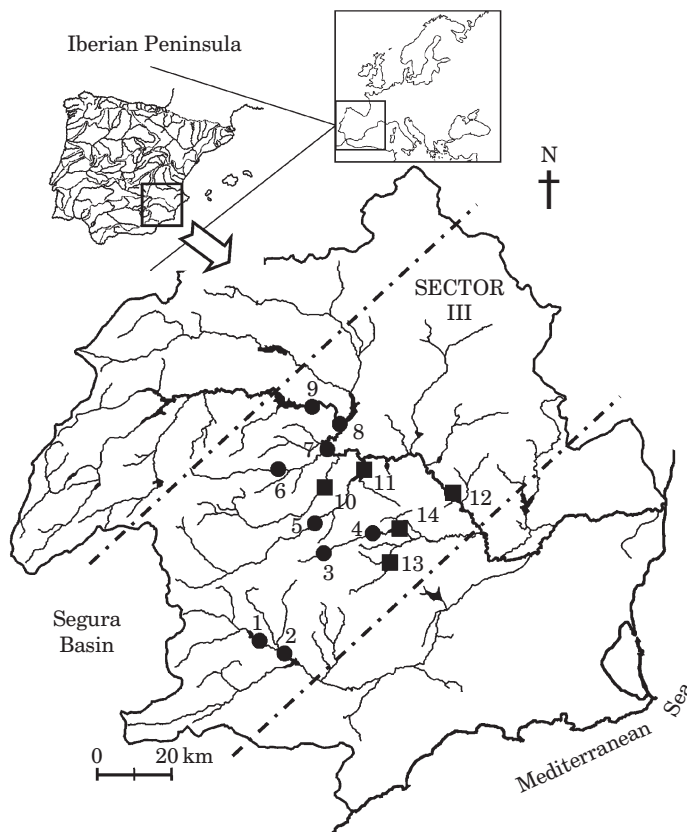
FIG. 1. Sampling sites from the Segura River basin in the south-east of the Iberian Peninsula. Streams (1, Luchena-1; 2, Luchena-2; 3, Mula-1; 4, Mula-2; 5, Quípar; 6, Benamor; 7, Segura-1; 8, Segura-2; 9, Segura-3) and reservoirs (10, Argos; 11, Alfonso XIII; 12, Ojos; 13, Pliego; 14, La Cierva).

A total of 1629 individuals from 14 sampling sites were analysed (927 from streams: Luchena, Mula, Quípar, Benamor and Segura and 702 from reservoirs: Argos, Alfonso XIII, Ojós, La Cierva and Pliego) (Fig. 1). Sampling sites were selected to survey the main flows of the Segura River basin with different hydrological regimes. Individuals were captured by electrofishing in streams and by passive fishing methods in reservoirs, both during November 1998, a month chosen to avoid the capture of prespawning and spawning fish (Torralva *et al.*, 1997) and, consequently, to ensure that any variation in body condition was not affected by gonad development (Herrera & Fernández-Delgado, 1994; Encina & Granado-Lorencio, 1997).

In streams, fishing was performed with standard AC electrofishing equipment based on a 1800 W motor (working voltage between 200 and 350 V, 2–3 A). Fish were removed from the lower to the upper part of each sampling stretch that was blocked off with barrier nets. Fishing in triplicate was carried out in an attempt to keep the effort constant.

In reservoirs, fish were caught with different types of sampling gear: simple monofilament nylon trawl-nets (12·5 m long, 1·80 m high) on the surface both running transversely from the reservoir edge and in the centre of the reservoir, and fyke-nets (prawn nets, 2 m length, 0·1 m entrance diameter) and minnow-traps (0·5 m length, 0·03 m entrance diameter) in the shallow upwaters of the reservoir. All of these passive fishing methods were set for *c.* 24 h.

After capture, fish were anaesthetized with benzocaine and standard length (L_S, ± 1 mm) and total mass (M, $\pm 0 \cdot 1$ g) were obtained *in situ* for each individual. Fish <75 mm [<2+ year age class, scale analysis (unpubl. data)] were excluded from the analysis to avoid possible differences in body shape between juveniles and adults (Murphy *et al.*, 1990) and to minimize measurement errors associated with weighing small fish in the field (Vila-Gispert & Moreno-Amich, 2001). Fish killed as a result of being trapped in the nets for a long time (*c.* 5% of captures, depending on the reservoir) were also excluded. The majority of fish (95%) were returned alive to the water.

Each sampling site was characterized by six environmental variables related to water quality (14 day mean values) and physical state of the habitat: conductivity (μs cm^{-1}), oxygen concentration (ppm), water temperature (°C), pH, seasonal water fluctuation and submerged vegetation (Table I).

Seasonal water fluctuation in streams was categorized as differences in flow, and in reservoirs as the percentage of the relationship between minimum and maximum water volume. The highest seasonal water fluctuation was found in streams that were reduced to small isolated pools during dry periods and the lowest seasonal water fluctuation was found in streams with relatively constant flow throughout the year. Seasonal water fluctuation in the reservoirs reached >100% in extreme cases, while other reservoirs showed variations of <10%. Stream submerged vegetation was classified as absent (no aquatic vegetation), little (covering <10% of the stretch), poor (covering 10–30%), disturbed (covering 30–60%) and developed (covering >60% of the stretch). In reservoirs the same classification of edge areas was applied.

STATISTICAL ANALYSES

The statistical analysis used to compare fish condition followed that used in previous studies on *Barbus meridionalis* Risso (Vila-Gispert *et al.*, 2000; Vila-Gispert & Moreno-Amich, 2001) and proposed by García-Berthou & Moreno-Amich (1993). The method is based on the application of univariate analysis of covariance (ANCOVA) using total M as the dependent variable and L_S as the covariate. The homogeneity of the regression coefficients (b, slopes) was tested with an ANCOVA design that analysed the pooled covariate-by-factor interaction. If this interaction (homogeneity of slopes) was not significant ($P > 0 \cdot 05$), standard ANCOVA was applied to test differences in the coefficient a (the *y*-intercept).

A stepwise multiple regression analysis was performed to determine the amount of variation in a associated with environmental variables. Bivariate relationships between environmental variables were also analysed using Pearson's correlations for quantitative variables and Spearman's correlations for categorical variables.

Statistical analyses were performed with SPSS® software package and a significant level of $P = 0 \cdot 05$ was accepted.

RESULTS

Barbel was the dominant fish species in the majority of sampling sites (80–100%). It was the only one living in four of the stream sampling sites and the dominant species in the rest, coexisting with *Chondrostoma polylepis* Steindachner, *Gobio gobio* (L.), *Squalius pyrenaicus* (Günther) and *Oncorhynchus mykiss* (Walbaum). Similarly, barbel was the dominant fish species in reservoirs, coexisting with *C. polylepis*, *Cyprinus carpio* L., *Carassius auratus* (L.), *Micropterus salmoides* (Lacépède) and *Gambusia holbrooki* (Agassiz).

Coefficients of the mass–length relationship in each population studied are presented in Table II and the results of the ANCOVA are shown in Table III. Coefficient b did not vary between sampling sites ($P = 0 \cdot 220$), whereas a varied significantly ($P < 0 \cdot 0005$). Benamor and Segura (streams) and Ojos and La Cierva

TABLE I. Habitat differences between sampling sites. In reservoirs, the values given for the physicochemical variables refer to the mean value of several surface measurements. Seasonal water fluctuation: 0 (isolated pools; water volume variation >100%), 1 (moderate; water volume variation between 10 and 100%) and 2 (continuous flow; water volume variation <10%). Submerged vegetation: 1 (absent), 2 (little), 3 (poor), 4 (disturbed) and 5 (developed)

Sampling site	Sub-basin	Conductivity ($\mu s\,cm^{-1}$)	Oxygen concentration (ppm)	Water temperature (°C)	pH	Seasonal water fluctuation	Submerged vegetation
Streams							
Luchena-1 (upstream)	Luchena	2620	6·44	23·5	8·48	1	1
Luchena-2 (downstream)	Luchena	2900	11·75	11·8	9·18	0	2
Mula-1 (upstream)	Mula	700	8·14	16·1	6·75	1	1
Mula-2 (downstream)	Mula	930	8·38	13·9	6·16	0	1
Quipar	Quipar	1310	7·66	6·1	9·14	0	5
Benamor	Benamor	50	11·70	6·4	9·45	1	4
Segura-1 (upstream)	Segura	560	9·94	13·4	8·12	2	2
Segura-2 (middle)	Segura	660	11·60	17·2	8·27	2	1
Segura-3 (downstream)	Segura	700	12·04	17·0	7·51	2	2
Reservoirs							
Argos	Argos	1700	8·71	17·3	7·25	1	1
Alfonso XIII	Quipar	3600	10·33	17·1	7·54	1	1
Ojos	Segura	500	8·55	16·5	8·71	2	3
Pliego	Mula	1900	6·98	17·0	8·05	0	1
La Cierva	Mula	600	7·46	16·1	8·10	1	2

TABLE II. Regression coefficients (a, b) $\pm$ 95% CL and correlation coefficients (r) of the ln-transformed mass–length relationship, and mean $\pm$ 95% CL standard length in each population studied

Sampling site	n	b (slope)	a (the y-intercept)	r	Mean $\pm$ CL L_S (mm)
Streams					
Luchena-1 (upstream)	118	2·95 $\pm$ 0·04	−11·11 $\pm$ 0·14	0·99	128·3 $\pm$ 10·3
Luchena-2 (downstream)	118	3·11 $\pm$ 0·10	−11·90 $\pm$ 0·20	0·98	114·6 $\pm$ 4·0
Mula-1 (upstream)	23	3·00 $\pm$ 0·05	−11·22 $\pm$ 0·22	0·99	110·3 $\pm$ 24·3
Mula-2 (downstream)	39	2·95 $\pm$ 0·05	−11·38 $\pm$ 0·16	0·99	139·6 $\pm$ 16·9
Quípar	87	2·99 $\pm$ 0·04	−11·21 $\pm$ 0·17	0·99	143·2 $\pm$ 10·5
Benamor	39	2·92 $\pm$ 0·08	−10·79 $\pm$ 0·27	0·98	93·3 $\pm$ 4·4
Segura-1 (upstream)	212	2·98 $\pm$ 0·03	−10·83 $\pm$ 0·15	0·99	171·7 $\pm$ 5·2
Segura-2 (middle)	42	2·94 $\pm$ 0·09	−10·93 $\pm$ 0·25	0·97	124·5 $\pm$ 4·5
Segura-3 (downstream)	249	2·99 $\pm$ 0·03	−10·51 $\pm$ 0·12	0·99	128·1 $\pm$ 2·9
Reservoirs					
Argos	27	2·95 $\pm$ 0·05	−11·07 $\pm$ 0·19	0·99	197·9 $\pm$ 25·0
Alfonso XIII	176	2·99 $\pm$ 0·03	−11·19 $\pm$ 0·15	0·99	266·5 $\pm$ 10·3
Ojos	205	2·94 $\pm$ 0·04	−10·82 $\pm$ 0·15	0·99	281·1 $\pm$ 7·1
Pliego	173	2·96 $\pm$ 0·04	−11·01 $\pm$ 0·18	0·98	234·1 $\pm$ 4·5
La Cierva	121	2·93 $\pm$ 0·06	−10·92 $\pm$ 0·23	0·98	249·4 $\pm$ 4·5

(reservoirs) had the highest fish condition as indicated by a (Table II). Most of the stream sampling sites showed a low fish condition value, while fish condition in reservoirs within the same sub-basin was higher than in the corresponding stream sampling sites. Upstream sampling sites showed higher fish condition than downstream sampling sites in the same sub-basin.

Stepwise multiple regression analysis indicated that seasonal water fluctuation accounted for most of the variation (51·9%) in a of the mass–length relationship (Table IV, Model 1). A second multiple regression model not involving seasonal water fluctuation indicated that water conductivity explained 35·3% of the variation in a (Table IV, Model 2). Oxygen concentration, water temperature,

TABLE III. ANCOVA analyses of the mass–length relationship in *Barbus sclateri*. All variables (dependent and covariate) were ln-transformed. Standard length is the covariate

Source of variation	F	d.f.	P
Preliminary design (test for interaction)			
L_S	38554·25	1, 1628	<0·0005
Sampling site	1·35	13, 1628	0·177
$L_S \times$ sampling site	1·28	13, 1628	0·220
Final design (no interaction)			
L_S	105577·50	13, 1628	<0·0005
Sampling site	49·24	13, 1628	<0·0005

TABLE IV. Stepwise multiple regression analysis used to predict coefficient a of the mass–length relationship from environmental variables

Environmental variables	Regression equations	Adjusted r^2	F	d.f.	P
Model 1					
Seasonal water fluctuation	$a = -11 \cdot 36 + 0 \cdot 30$ (seasonal water fluctuation)	0·519	12·954	1,13	0·004
Model 2 (excluding seasonal water fluctuation)					
Water conductivity	$a = -10 \cdot 80 - 0 \cdot 0018$ (water conductivity)	0·353	6·554	1,13	0·025

pH and submerged vegetation did not explain variation in a among sampling sites. Bivariate relationships between a and environmental variables, and among the latter, are presented in Table V. Of note is the significant relationship between seasonal water fluctuation and water conductivity, and between water conductivity and submerged vegetation.

DISCUSSION

A critical component in interpreting fish condition data is the application of the correct statistical methodologies when collecting and analysing the data (Patterson, 1992). Assuming that the mass–length slope does not vary between near populations and that the slope is homogeneous for populations on a local level, the analysis of mass–length regressions provides a good alternative to the relative mass indices (ratio-related techniques) for investigating inter-population variations in fish condition (Sutton *et al.*, 2000; García-Berthou, 2001).

The condition of barbel differed between the populations studied. Differences in coefficient a of the mass–length relationships were probably caused by differences in environmental conditions. The sampling period was both short and in November, which avoided the capture of prespawning and spawning fish and thus ensured that differences in a were not related to seasonal variations in

TABLE V. Correlation matrix of coefficient a (*y*-intercept from mass–length regression) and environmental variables (Pearson's or [s]Spearman's correlation coefficients) for all sampling sites. (*$P < 0·05$)

Environmental variables	a	Conductivity	Oxygen concentration	Water temperature	pH	Seasonal water fluctuation
Conductivity	−0·59[*]					
Oxygen concentration	0·08	−0·10				
Water temperature	0·14	0·32	−0·32			
pH	0·01	0·01	0·20	−0·42		
Seasonal water fluctuation	0·73[s*]	−0·56[s*]	0·37[s]	0·35[s]	0·00	
Submerged vegetation	0·40[s]	−0·51[s*]	0·24[s]	−0·70[s*]	0·68[s*]	0·09

the condition of this species, variations confirmed by several studies in the south of the Iberian Peninsula (Herrera & Fernández-Delgado, 1992; Rodríguez-Ruiz & Granado-Lorencio, 1992; Torralva *et al*., 1997). Although fish size could be an important factor affecting fish condition (Pope & Willis, 1996), the homogeneity of the slopes of the mass–length relationship obtained for the populations studied indicated that condition was independent of fish body form (Winters & Wheeler, 1994).

The ecological variable that accounted for most of the variation in *a* of the mass–length relationships was seasonal water fluctuation, which is directly related to the climatic conditions of the region (Vidal-Abarca *et al*., 1987). Stream sampling sites with a continuous water flow and reservoirs showing lower temporal water-level variations provided the highest values of *a*, demonstrating the better fish condition. In previous studies on *B. meridionalis* inhabiting streams (Vila-Gispert *et al*., 2000; Vila-Gispert & Moreno-Amich, 2001), periodic scouring and low flows were seen to be the most important factors negatively affecting fish condition.

The stream sampling sites, which showed drastic intermittent flow regimes (high or moderate seasonal water fluctuation: Luchena, Mula, Quípar and Benamor), contained small pool refugia and exhibited substantial temporal variations in their physical and chemical characteristics (Vidal-Abarca, 1985). Except in the Benamor Stream, where the effects were less drastic, flows ceased in the summer and the streams were reduced to small isolated pools where fish were concentrated. In such situations, fish density increases and competition for space and food may become important (Matthews, 1998; Spranza & Stanley, 2000). Associated with these changes in environmental conditions, basic changes may occur in life history attributes (Schlosser, 1990). In the present study, sampling sites in intermittent streams provided the lowest fish condition values, while sampling sites with a continuous water flow presented the highest values. Torralva *et al*. (1997) reported that females of the same species from a regulated sampling site with continuous water flow showed higher condition values than females from non-regulated sampling site with highly variable water levels.

The same pattern was observed in reservoir sampling sites. Ojos, with the lowest seasonal fluctuation in water levels, had the highest fish condition. Granado-Lorencio (1987) found that variations in average depth and shore-line development were related to biomass and fish status in reservoirs of the south of Iberian Peninsula. Seasonal water-level fluctuations were high in most of the reservoirs sampled, so the variations in depth and shore-line were great and, seemingly, an important factor affecting fish condition.

The sampling area is one of the most important irrigated agricultural areas of the Iberian Peninsula (León & Sánchez, 1995), so agrochemical and nutrient inputs (*via* run-off) are high. This, added to the saline character of the substratum (Vidal-Abarca *et al*., 1995), causes high values of water conductivity in surface waters. Indeed, water conductivity was the most significant variable in the second multiple regression model (Table IV) and fish condition was greatest in sampling sites with low water conductivity.

Downstream sampling sites showed higher values of water conductivity (Table I) because, in each sub-basin, the input levels increases and, at the

same time, the flow decreases because water is normally extracted for irrigation purposes. It is only to be expected, then, that downstream sampling sites showed lower fish condition values (Table II). This agrees with the results obtained for the same species in the Guadalete River (southern Spain) (Rodríguez-Ruiz, 1992), where the highest fish condition was observed in the upper sampling sites with the lowest water conductivity. Stream sampling sites with continuous flows and reservoirs with low water-level variations showed lower water conductivity values because of higher flow rates and water volumes, respectively, two factors that reduce nutrient and salt concentrations. High conductivity and salinization of surface waters is a common problem in semi-arid zones (Petr & Mitrofanov, 1995), but has not been studied intensively in the Segura River basin.

Because of anthropogenic water regulation for agricultural purposes, the Segura River presents a modified flow dynamic with continuous water flow and low temporal fluctuations. The present results show that the 'best' fish condition was found in the Segura sampling sites and in the Ojos, which is the only sampling reservoir located on the Segura River itself, the rest being located on tributaries. The results agree with Torralva *et al.* (1997), who reported that females of the same species from a regulated sampling site with a continuous water flow showed higher condition values than females from non-regulated sampling sites with highly variable water levels. Although oxygen concentration was not found to be a good predictor of fish condition in the present study, in agreement with Vila-Gispert *et al.* (2000) and Vila-Gispert & Moreno-Amich (2001), it is possible that this variable, which normally takes on higher values in constantly running waters, had an important effect.

The sampling area is one of the largest irrigated areas of the Iberian Peninsula, consequently the anthropogenic influences on stream flows are drastic. In this way, it is interesting to show how two sorts of anthropogenic influence (*i.e.* water diversion that results in isolated pools or increases environmental stress in habitats during summer *v.* stream flow regulation that results in continuous flow) for the same purpose (*i.e.* agricultural production) result in different effects on the fish condition. From a conservation biology standpoint, it is interesting that *B. sclateri* showed higher condition values in the regulated sampling sites. It is not possible to know if stream flow regulation has really improved fish condition in this portion of the species' range as there are no historical data.

The results suggest that condition of barbel in semi-arid aquatic systems depends primarily on seasonal water fluctuation (flow and water level), which in turn affects water conductivity. Streams with a continuous water flow and reservoirs with low water-level variations, which showed lowest conductivities, produced fish with a better condition. Consequently, the hydrological management of the basin and the saline character of the substratum in the area studied both affect fish condition. These results should be considered when fish populations are subjected to sports fishing regulations, recovery programmes or any other management activity.

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